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Flutter and buckling characteristics and active control of sandwich panels with triangular lattice core in supersonic airflow

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A B S T R A C T

Sandwich structures with lattice core are novel composite structures, but the aeroelastic behaviors of them have not been fully studied. This paper is devoted to investigate the flutter and buckling properties of sandwich panels with triangular lattice core in supersonic airflow, and the active flutter and buckling control are also carried out, which can provide theoretical basis for the use of sandwich structures in the design of aircrafts. The unsteady aerodynamic pressure is evaluated by the supersonic piston theory in which the yawed flow angle is taken into account. Hamilton's principle with the assumed mode method is applied to formulate the equation of motion of the structural system. The active controller is designed by the displacement feedback method. Aeroelastic characteristics of the sandwich panels are studied, and the influences of the aerodynamic pressure on the frequency and mode shape of the panel are analyzed. The effects of yawed flow angle on the flutter properties of the sandwich panel are also analyzed. When considering the external in-plane load, the buckling behaviors of the sandwich panel are investigated. Moreover, the flutter and buckling properties between the sandwich and equivalent isotropic panels are compared to show the superior aeroelastic properties of the sandwich panels. The effects of piezoelectric patch placements on the active flutter control are analyzed. The optimal locations of piezoelectric actuator and sensor pairs are obtained by the genetic algorithm. The present study verifies that the sandwich structures have different aeroelastic and flutter suppression properties, which is useful in the research of lightweight sandwich materials.

1. Introduction

Recently, lightweight lattice sandwich structures are widely used in the naval and aerospace industries due to their beneficial properties of high strength-to-mass ratio. Moreover, they also possess the strong abilities of energy absorption, heat insulation as well as noise reduction. Consequently, many literatures have focused on the investigations of the sandwich structures. D'Alessandro et al. [1] reviewed the most significant works in literature about the acoustic behavior of sandwich panels. Qian et al. [2] described an approach on the prediction of sound transmission loss for a finite sandwich panel with honeycomb core. Franco et al. [3] presented the optimization of various innovative sandwich configurations for minimization of their structural acoustic response. Honeycomb and truss cores were considered. Zhang et al. [4] developed a method of manufacturing sandwich structures with carbon fiber reinforced polymer tetrahedral lattice truss core by thermal expansion silicon rubber mould. Shiau and Kuo [5] carried out the vibration analysis of thermally buckled sandwich plates by developing a triangular plate element with high precision. Zhou and Croker [6] developed the governing equations of the forced vibration for asymmetric sandwich panels based on the energy relationships. Franco et al. [7] dealt with the numerical analysis of some configurations of sandwich panels using the finite element method, and illustrated how truss-like cores with randomized stiffness can be used to modify the vibroacoustic performances. Zielinski et al. [8] tested the feasibility and performance of the passive and active acoustic attenuations of an active sandwich panel with a poroelastic core. Ruzzene [9] investigated the vibration characteristics of truss core sandwich beams using the finite element method. The sound radiation in the sandwich beams was also analyzed.

Xiong et al. [10] presented original analytical and experimental

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studies for the response and failure of sandwich panels with pyramidal truss core. Lou et al. [11] carried out a dynamical analysis for sandwich structures. The influences of local damage on the natural frequencies and modes of the structure were studied. Kim and Han [12] proposed a hybrid analytical/finite element method to identify the acoustic characteristics of honeycomb sandwich panels. Based on the experiment and simulation, Wang et al. [13] studied the low-velocity impact behaviors and residual tensile strength of sandwich structures with lattice core. Yin et al. [14] proposed a novel hybrid truss construction concept that incorporates a second-phase core material into trusses of carbon fiber composite pyramidal lattice structures. Yu and Cleghorn [15] presented the free flexural vibration analysis of simply supported symmetric rectangular honeycomb panels using the classical plate theory, Mindlin's improved plate theory, and Reddy's third-order plate theory. Liu et al. [16] investigated the effects of temperature on the mechanical behaviors of composite rods and carbon fiber composite truss cores. They also conducted an experiment to investigate the effect of high temperature exposure on the mechanical properties of carbon fiber composite sandwich panel with pyramidal truss core [17].

For the lattice sandwich structure in supersonic airflow, its aeroelastic behaviors will be significant for the whole structural system. Aeroelastics is a subject that mainly focuses on the fluid-structural interaction. Many literatures have conducted the aeroelastic analysis [18]. McNamara and Friedmann [19] reviewed the status on the aeroelasticity and aerothermoelasticity in hypersonic airflow, and pointed out their future directions. Jansen [20] analyzed the aeroelastic characteristics of laminated cylindrical shells based on a perturbation expansion method. Shiryayev and Slater [21] applied the minimum model error system identification method to formulate the nonlinear state space models of a fluttering panel. Sabri and Lakis [22] predicted the flutter boundaries of circular cylindrical shells applying a hybrid finite element formulation. Abbas et al. [23] investigated the aerothermoelastic behaviors of skin curved panels with static and dynamic edge movability effect in supersonic flow. Shiau and Lu [24] analyzed the nonlinear flutter behavior of a two-dimensional simply supported symmetric composite laminated plate at supersonic Mach number. Song and Li [15–27] studied the aeroelastic properties of composite laminated and lattice sandwich panels in supersonic airflow.

Although there are some literatures that have studied the vibration performances of sandwich structures, and the aeroelastic behaviors of structures in supersonic airflow have been extensively researched, few researches have focused on the panel flutter characteristics of lattice sandwich structures. Therefore, in this investigation, the flutter and buckling behaviors of sandwich panels with the triangular lattice core are studied, and the active flutter and buckling control are also carried out, in order to provide theoretical basis for the use of sandwich structures in the design of aircraft. The equation of motion of the sandwich panel is formulated by Hamilton's principle with the assumed mode method. The active controller is designed by the displacement feedback method. The influences of the aerodynamic pressure on the frequency and mode shape of panels are studied. The effects of yawed flow angles on the flutter properties of the sandwich panel are also analyzed. The buckling behaviors of the sandwich panel subjected to the external in-plane loads are investigated. Moreover, the flutter and buckling properties between the sandwich and isotropic panels are compared so that the superior aeroelastic properties of the sandwich panels can be displayed. The effects of piezoelectric patch placements on the active flutter control are analyzed. The optimal locations of piezoelectric actuator and sensor pairs are obtained by the genetic algorithm. This investigation will be useful in the research on the aeroelastic analysis and flutter control of lightweight sandwich materials.

2. Formulation for the equation of motion

The sandwich panel with the piezoelectric actuator and sensor bonded on the top and bottom surfaces is shown in Fig. 1. As it is displayed in the figure, the panel is composed of face sheets, piezoelectric actuator and sensor pairs, and triangular lattice core. The length and width of the panel are a and b. The coordinates of piezoelectric patches are (x_1, x_2, y_1, y_2). The thicknesses of the face sheets, piezoelectric material and lattice core are denoted by h_f, h_p and h_c.

Since the face sheets and piezoelectric material are relatively thin, classical plate theory (CPT) is applied in the structural modeling. As for the lattice core, it is modeled by the first-order shear deformation theory (FSDT) [28]. According to the relationship of the deformation, displacement fields of each part of the structural system are given as [27] (here the thickness of the sandwich structural system remains constant during deformation, and the displacement fields u_0, v_0 and w are independent of coordinate z)

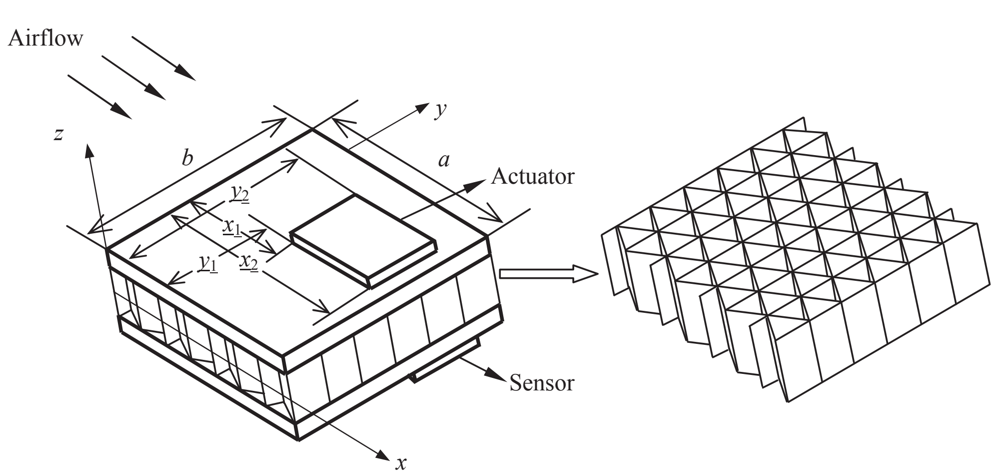

Fig. 1. The sandwich panel with triangular lattice core in supersonic airflow.